Lagrangian Floats For CBLAST

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LONG-TERM GOALS

I seek to understand the dynamics of the ocean boundary layer beneath hurricanes and the resulting air-sea fluxes which drive it with the goal of improving ocean models at high wind speed.

OBJECTIVES

To measure turbulence properties and fluxes in the ocean boundary layer beneath hurricanes and relate them to hurricane properties and fluxes measured by others. To model the measured boundary layer properties using Large Eddy Simulation (LES) techniques with the twin goals of testing the models and investigating the boundary layer physics using the models.

APPROACH

Measurements

Neutrally buoyant Lagrangian floats were air-deployed into hurricanes during the 2002, 2003 and 2004 hurricane seasons. The floats are designed to be used in energetic turbulent flows such as those found in the top and bottom boundary layers of the ocean. A combination of accurate ballasting, compressibility matched to that of seawater and high drag is used to make these floats follow the motion of water parcels accurately (D'Asaro 2003). Water velocity is inferred from the motion of the floats; high frequency fluctuations in velocity can be used to infer dissipation rate (Lien and D'Asaro, 2005) and covariance of vertical velocity with scalars can be used to compute heat and other fluxes (D'Asaro, 2004).

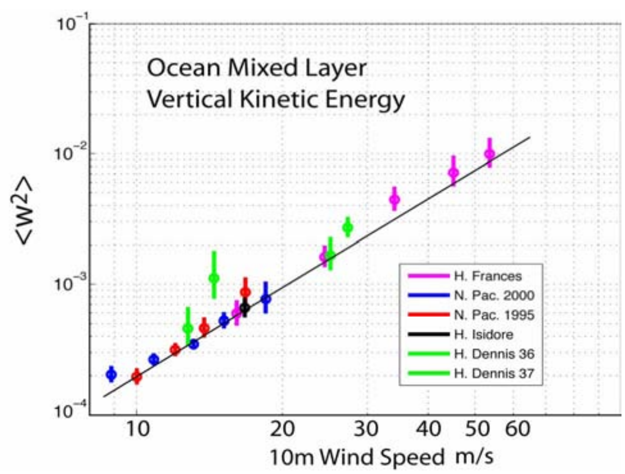

Figure 1. Vertical kinetic energy measured by Lagrangian floats as a function of wind speed. An excellent correlation is observed over a range of wind speeds from 8 to 60 m/s.

Modeling

The LES modeling work is being conducted by Ramsey Harcourt and Eric D'Asaro. Our starting point is a standard LES scheme using a subgrid closure with active kinetic energy as implemented in Harcourt et. al (2002). The standard implementation of vortex force

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interaction between surface wave Stokes drift (Skyllingstad and Denbo, 1995; McWilliams *et al*, 1997) is modified to simulate the mean Lagrangian velocities measured by floats in the ocean. Careful attention has been paid to the role of surface waves in forcing boundary layer turbulence. This model includes the ability to simulate the trajectories of both perfectly Lagrangian and realistically imperfect floats. This work is parallel to similar NSF funded work on boundary layers at lower winds.

The modeling is focused on explaining the remarkably good correlation between vertical kinetic energy measured by Lagrangian floats and wind stress (Fig. 1) over a wide range of wind speeds. This correlation is surprising because most previous theory predicts a strong dependence of vertical kinetic energy on the properties of the surface waves. However, previous work has mostly not used realistic and consistent formulations of stress and winds. We therefore force the LES model forcing over a natural parameter range of wave age and wind speed representative of open ocean storm forcing, using the surface drag formulation of Donelan et al (1993) and the directional wave spectrum of Donelan et al (1985), modified at high frequencies after Banner (1990). Results for young seas are extended into hurricane force winds to test recent results on the saturation of drag coefficients at extreme wind speeds (Donelan et al 2003). A set of model runs was made with the surface stress and Stokes drift computed for developing and mature wind seas characterized by wave age C_P/U_{10}, where C_P is the spectral peak phase speed. We then investigated the scaling of vertical kinetic energy as a function of these parameters.

WORK COMPLETED

A paper describing the overall results from CBLAST is in press in the *Bulletin of the American Meterological Society*. The PI, with help from other CBLAST investigators, wrote the part of the paper describing the float and drifter components.

The first CBLAST float results are described in two papers on gas exchange in Hurricane Frances in press in *J. Marine Systems.*

A paper describing the scaling of mixed layer vertical kinetic energy in the LES model has been submitted to *Ocean Modelling*. A second manuscript, comparing these results with the float data, is in preparation.

RESULTS

Fig. 2 shows the scaling of the model runs. Vertical kinetic energy, scaled by wind stress, is a function of a modified turbulent Langmuir number

$$La_{St} = \left[u^* / \left(\left\langle u^S \right\rangle_{SL} - u^S_{ref}\right)\right]^{1/2},$$

based on a near-surface average $\left\langle u^S \right\rangle_{SL}$ of the Stokes drift u_s. A reference level u^S_{ref} from within the lower mixed layer is subtracted because vortex force production must vanish for a mixed layer with uniform Stokes drift

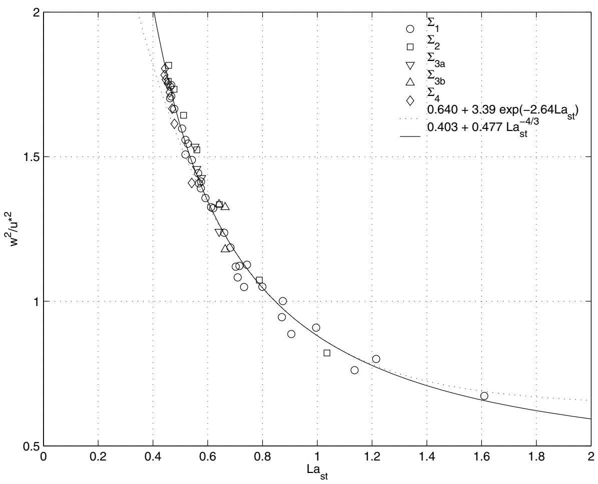

Figure 2. Scaling of vertical turbulent kinetic energy as a function of the surface layer Langmuir number. A tight relationship is between the excess vertical TKE, i.e. the part above that expected for a boundary layer with no waves, scaled by the friction velocity and the Langmuir number associated with the Stokes drift from the upper 20% of the mixed layer.

Fig. 3 shows this theory applied to the data in Fig. 1. The vertical axis is the vertical kinetic energy scaled by wind speed, but cast here in terms of a constant drag coefficient. The colored lines are the scaling derived from the LES modeling. As expected from previous work, the scaled vertical kinetic energy increases with wind speed for surface wave fields with a constant wave age (wave age is shown by the color on the lines and the data points). When wave age is taken into account, the data falls close these model predictions. However, as shown in the lower panel, the wave age decreases with wind speed, resulting in a nearly constant value of scaled kinetic energy over a broad range of wind speeds.

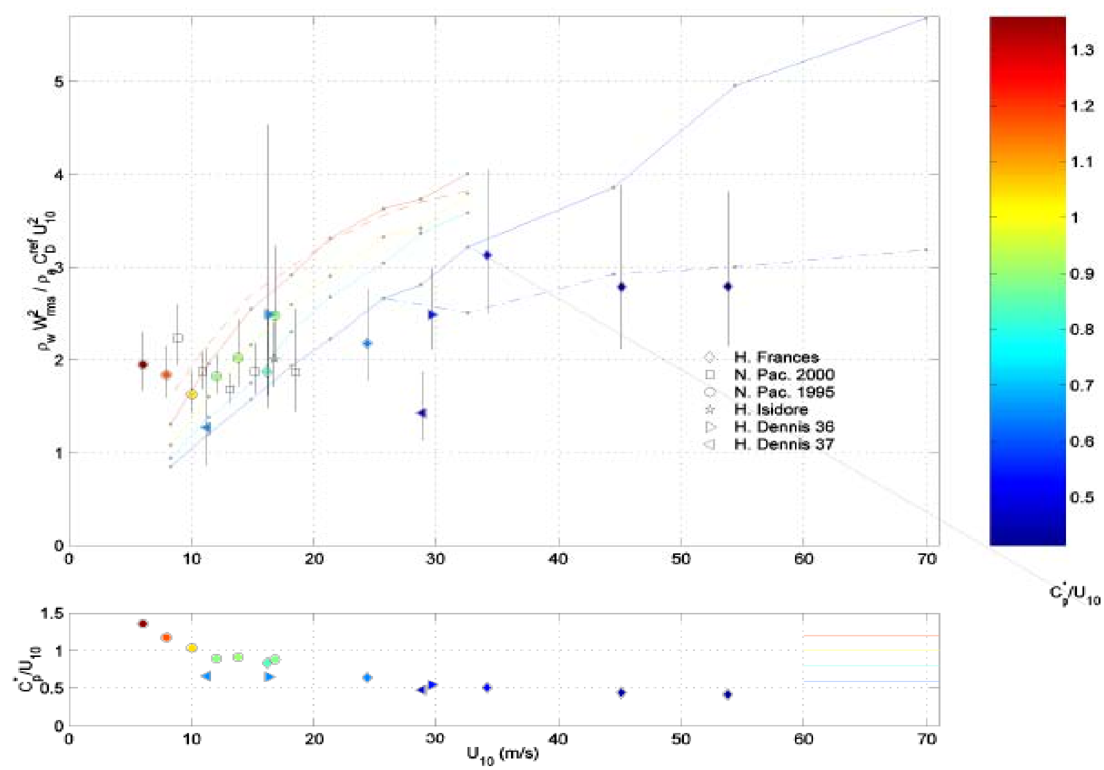

Fig. 3. Comparison of scaling theory for LES model and float data, as described in the text.

The simulations also reveal a clear signature of surface wave forcing in the profile of vertical kinetic energy as shown in Fig. 4. The LES results show that two factors control the large-eddy scale in the boundary layer: the distance from the wall, as in a normal turbulent boundary layer, and the vertical scale of the Stokes drift profile. Normally, the first is most important and the maximum in turbulent kinetic energy occurs very near the surface. However, at hurricane force winds, the Stokes drift depth dominates and the eddies become larger and the maximum in kinetic energy occurs at depth. Fig. 4 shows this effect in the data.

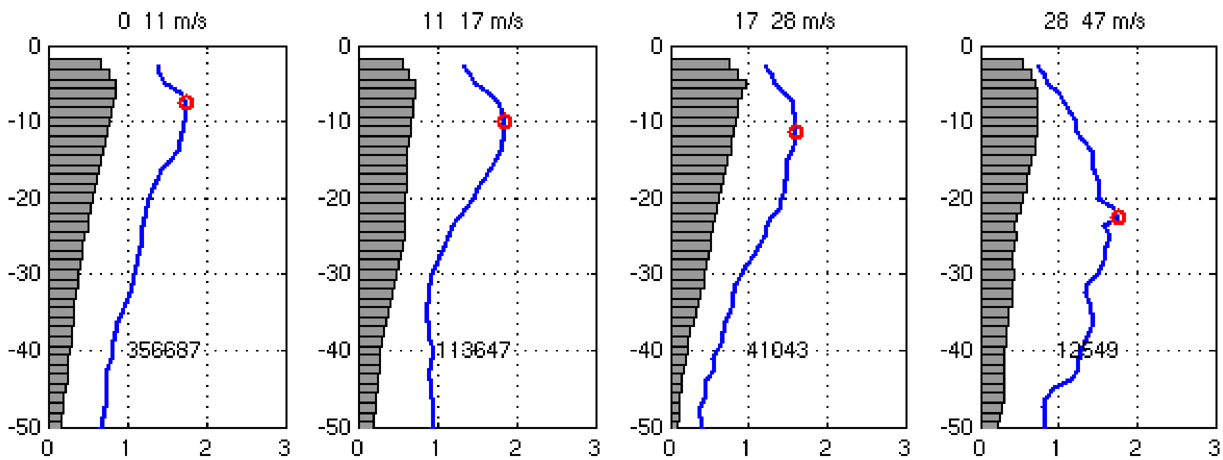

Fig. 4. Profiles of vertical kinetic energy, scaled by u*, grouped by wind speed. At hurricane winds, the maximum is deeper.

In summary, we have made the first comprehensive study of the scaling of turbulent kinetic energy in the wind forced ocean mixed layer based on both models and data.

- Surface waves are clearly important in forcing boundary layer turbulence. Turbulent intensities are roughly double that expected without waves.

- The deepening of the vertical TKE maximum with wind clearly demonstrates the effect of waves.

- Despite the role of waves, the turbulent kinetic energy scales accurately with wind stress. This is due to two compensating effects. Dynamically, kinetic energy increases with wind speed, but decreases with wave age. Empirically, wave age decreases with wind speed, as higher winds generally blow for a shorter period of time and for shorter distances.

- The good empirical correlation of vertical TKE with wind stress may not hold in all environments, particularly in coastal areas or possibly hurricanes with abnormal relationships between wave age and wind.

- Under hurricane winds, the large eddies of the boundary layer are controlled by wave scales, probably making them more effective at mixing.

- These simulations have neglected wave breaking as a source of TKE. This suggests that breaking is not an important source of TKE for the bulk of the mixed layer.

IMPACT/APPLICATIONS

These results should finally allow closure models of the mixed layer to be tested against both turbulent as well as mean properties. This should enable significant evolution in these models, hopefully making them more robust.

TRANSITIONS

None

RELATED PROJECTS

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